# CONTAMINATION CONTROL CONSIDERATIONS FOR THE NEXT GENERATION SPACE TELESCOPE (NGST)

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## ABSTRACT

The NASA Space Science Program, in its ongoing mission to study the universe, has begun planning for a telescope that will carry on the Hubble Space Telescope's exploration. This telescope, the "Next Generation Space Telescope" (NGST), will be 6-8 meters in diameter, will be radiatively cooled to 30-60 Kelvin in order to enable extremely deep exposures at near infra-red wavelengths, and will operate for a lifetime of 5-10 years. The requirement will be to measure wavelengths from 1-5 microns, with a goal to measure wavelengths from 0.6-30 microns. As such, NGST will present a new contamination control challenge.

The Goddard Space Flight Center (GSFC) performed one of three preliminary feasibility studies for the NGST, presenting a telescope with an 8 meter, deployable primary mirror and a deployable secondary mirror. The telescope would be radiatively cooled, with the optical telescope assembly (OTA) and the science instrument module (SIM) isolated from the warmer spacecraft support module (SSM). The OTA and the SIM would also be shielded from sunlight with an enormous, inflatable sunshield. The GSFC telescope was designed for launch on an Atlas IIAS, which would require launching the telescope in a stowed configuration, with the SSM, antennae, sunshield, primary mirror "petals", and secondary mirror deployed once on-orbit. The launch configuration and deployment scenario of an exposed telescope measuring near infrared and cooled to 30-60K are the factors presenting contamination hazards to the NGST mission.

Preliminary science requirements established are: <20% reflectance decrease on optical surfaces over the wavelength range, and <0.3% obscuration of optical surfaces. In order to meet these requirements, NGST must be built and launched with careful attention to contamination control. Initial contamination control design options include strict selecting of materials and baking out of hardware down to the component level, minimizing or eliminating exposure of the OTA to sunlight or earth albedo during deployment and early on-orbit operations, cleaning of the primary and secondary mirrors at the launch site, cleaning of the launch vehicle fairing, locating thrusters and vents on the warm side of the sunshield only, and the possibility of including a deployable cover if that is shown to be necessary.

**Key Words:** contamination, infra-red optics, Next Generation Space Telescope, space deployable mirror, inflatable

## 1. DESCRIPTION OF A POSSIBLE NGST

In order to examine the feasibility of an NGST with the requirements described above; various designs have been developed. The design considered in this paper is based on the concept developed by GSFC[1] and is pictured in Figure 1.

The sunshield shown is 28 meters long, 14 meters wide, and would be deployed with 8 inflatable booms. The shield provides a barrier from sunlight in addition to passive cooling down to 60K. The SSM, which is located on the sun side of the shield, contains the attitude control system, solar arrays, and communications.
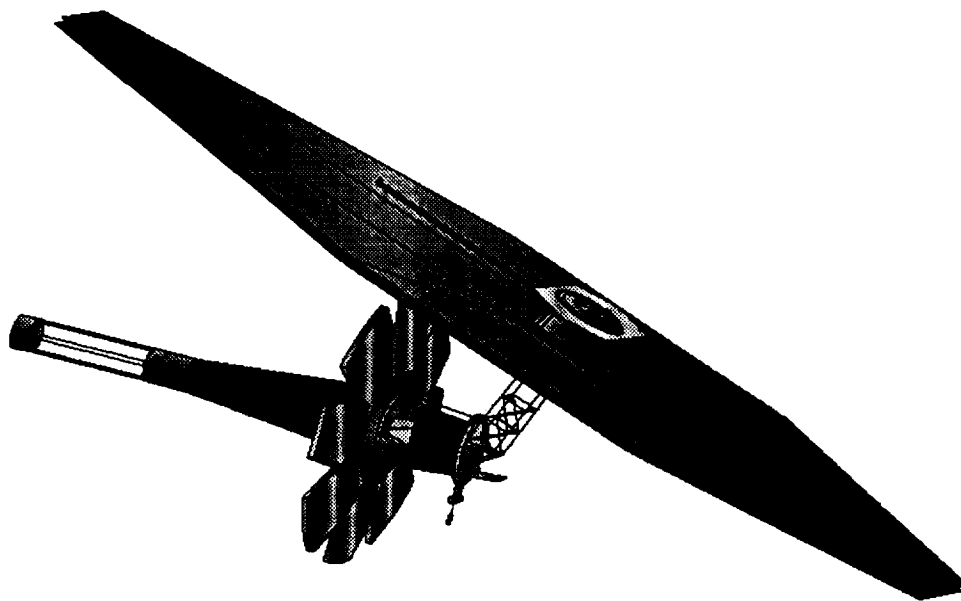
Figure 1 - The Next Generation Space Telescope, as conceived by GSFC

The science instrument module and the optical telescope assembly are located on the deep space side of the shield, separated from the warmer spacecraft by the sunshield and an isolation truss which would be deployed on orbit. The SIM complement includes an F/24 diffraction limited near infrared (NIR) camera, a multi-object spectrograph, a 349 actuator deformable mirror, and a fine steering mirror for line of sight jitter control. The OTA begins with the primary mirror, which is an 8-meter, ultra-lightweight, F/1.25 deployable mirror with active (actuator) control, and a 7' x 7' field of view. The secondary mirror is a 3 degree of freedom articulated, 0.72 meter, F/1.3 deployable mirror. The rest of the OTA is located inside the SIM.

## 2. SCIENCE AND CONTAMINATION REQUIREMENTS

Preliminary science requirements established are for <20% reflectance decrease on optical surfaces over the entire wavelength range and <0.3% obscuration of optical surfaces. These requirements translate to the following molecular and particulate contamination requirements.

### Molecular Requirement

Achieving <20% reflectance decrease over the range of 1-5 microns does not present an unusual challenge, but with the goal to measure down to 0.6 microns, the difficulty becomes much greater from a molecular contamination perspective. The concern arises chiefly because the primary and secondary mirrors will be exposed to sunlight and earth albedo, which will cause molecular contamination to polymerize. Based on tests performed for the Geostationary Operational Environmental Satellite (GOES), polymerized hydrocarbons have a dramatic effect on the measurement of wavelengths that are less than 1 micron. As illustrated in Figure 2, 50Å of carbon (representative of polymerized hydrocarbons) deposited on a mirror will cause a 5% reflectance loss on that surface at 0.6 microns. With the light reflecting off of two exposed mirror surfaces on NGST, 50Å of carbon would cause a 20% loss in reflectance.

Additional laboratory tests performed for GOES demonstrated that a maximum of 20% of hydrocarbons (or non-volatile residue, NVR) would polymerize when exposed to UV. Therefore, in order to assure that there will be <50Å of polymerized hydrocarbons on the primary and secondary mirrors after exposure to UV, the preliminary allowable molecular contamination requirement for NGST is that there be <250Å NVR on all optical surfaces prior to fairing separation.
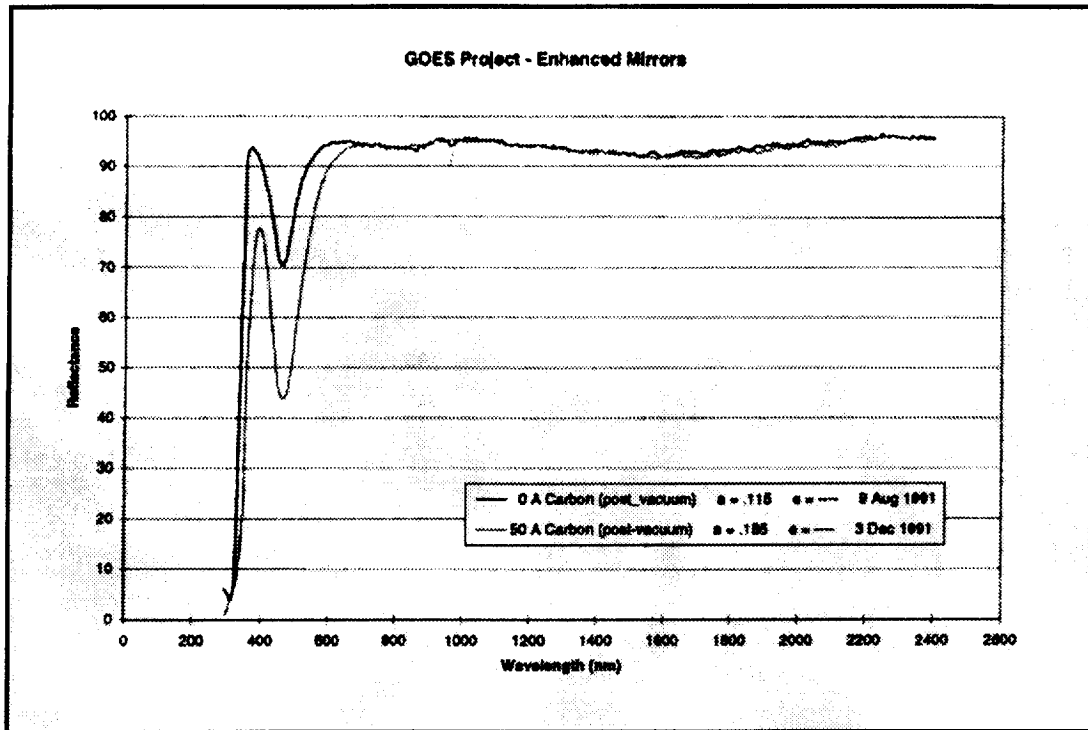
Figure 2    GOES Scan Mirror Reflectance Degradation as a Result of Polymerized Hydrocarbons

This requirement is very conservative. It is made with the assumption that all of the NVR on the mirror will be exposed to sunlight and/or earth albedo long enough for maximum polymerization to take place. Once the launch, deployment, and cruise to L2 sequences have been determined, the requirement will be re-evaluated. The strictness of the preliminary requirement serves to emphasize the importance of minimizing exposure to UV when deployment sequences are evaluated.

In addition, further reflectance analyses will be necessary for NGST as well. The tests performed for GOES and shown in Figure 2 used mirrors coated with aluminum and $SiO_2$. While this is similar to NGST's current plan for polished silver or gold, once a specific coating is chosen for NGST, reflectance tests will need to be performed on a mirror with the same coating. Additional degradation tests shall be performed both with carbon and with unpolymerized hydrocarbons as representative contamination. Such tests will also be performed in order to evaluate potential coatings. For example, the GOES mirror coating was selected to maximize reflectance at 0.6 microns, while sacrificing reflectance at 0.5 microns. There are many scientists proposing that NGST science include measurements down to 0.5 microns, which would then affect the development of a mirror coating. Finally, unpolymerized NVR will be important from a molecular species standpoint, because different species have absorption bands as high as 0.5 microns. Any such species would be strictly forbidden for use on the telescope side of NGST.

## Particulate Requirement

Obscuration, or the percent area blocked by particles, is the issue driving particulate contamination. A total of 0.3% obscuration over the 10-year life of NGST has been established, with the expectation that over a lifetime as long as 10 years, 0.2% obscuration will result from micrometeorite erosion. This leaves 0.1% margin for obscuration due to particulate contamination.

Particulate contamination is expected to accumulate during operations, during the launch phase, and during on-orbit deployments. A contamination analysis performed for GOES/Atlas[2] determined that the Atlas would contribute 0.005% obscuration to the GOES surfaces during launch. This leaves 0.095% obscuration that can be permitted on NGST spacecraft surfaces prior to launch, which corresponds to Level 375 per Mil-Std-1246 - as shown in Figure 3. The particle geometry for

spacecraft contamination in this calculation was considered to be that of a cylinder-hemisphere. Finally, future tests will need to be performed to assess particle redistribution that may be induced during deployment.
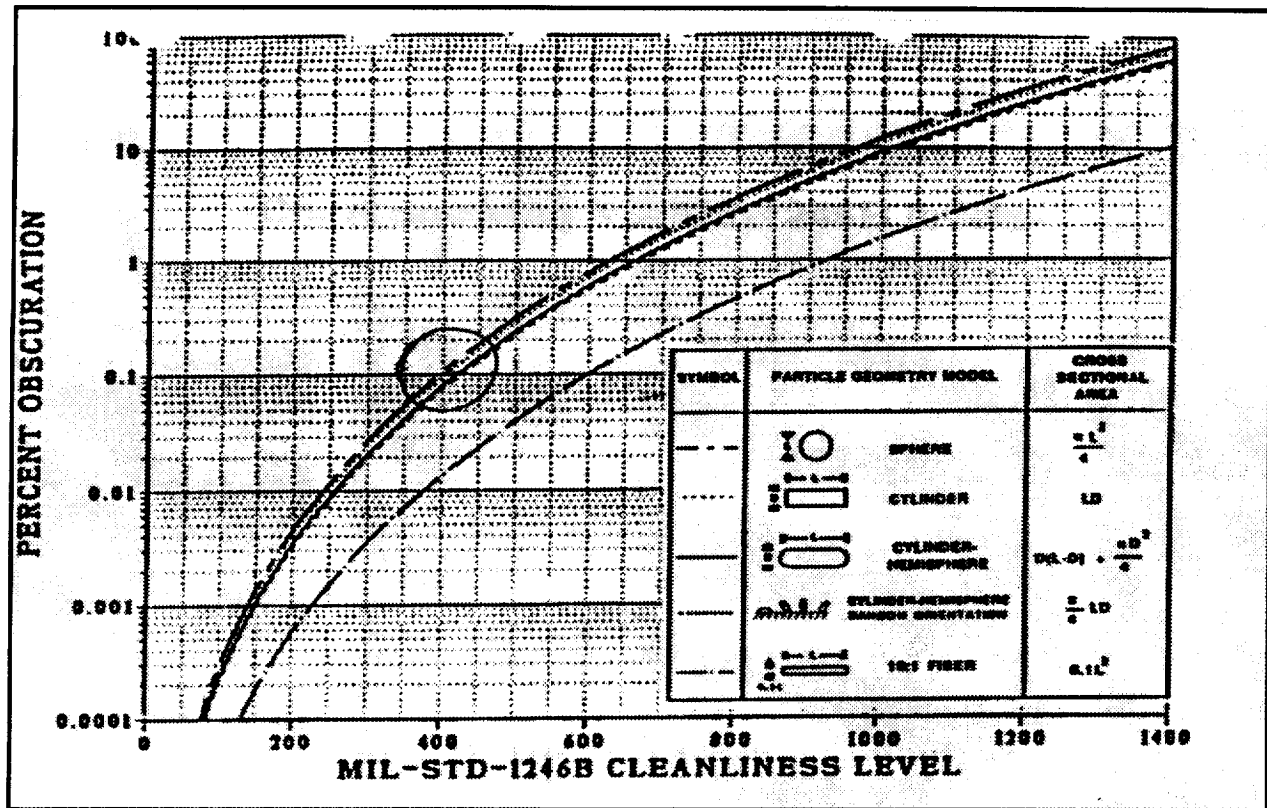


Figure 3   Obscuration as a Function of Particulate Contamination

## 3. CONTAMINATION CONTROL DESIGN

In order to meet the molecular and particulate requirements defined above, NGST must be built and launched with careful attention to contamination control. Initial contamination control design options embrace practices that have become standard in any contamination sensitive program. For instance, materials used shall be strictly controlled, and any new materials proposed will be evaluated for acceptability at their worst case on-orbit temperatures. Flight hardware will undergo thermal vacuum bakeout monitored by quartz crystal microbalances (QCMs) at several levels of assembly, starting from the component level. Because of the numerous deployments in the GSFC concept, mechanisms must embody only low-outgassing lubricants and must be fabricated in low particle-generating configurations.

As previously stated, the new challenge in NGST is that of controlling contamination for the primary and secondary mirrors, as discussed below.

### Mirror Contamination Issues

The huge, exposed primary mirror presents new problems for contamination control. The first is that the mirror must be cleanable, and cleaned at the last possible opportunity before launch. The GSFC design assumes use of an Atlas IIAS launch vehicle, therefore the final cleaning opportunity would be just prior to encapsulation. This would be in a processing building at the launch site, where Atlas fairing encapsulation takes place prior to transport to the Atlas gantry. The fairing would also require cleaning at the same time. According to the Atlas contamination analysis performed for GOES[2], the Atlas fairing can be cleaned to 0.005% obscuration with $CO_2$ and other methods of cleaning.
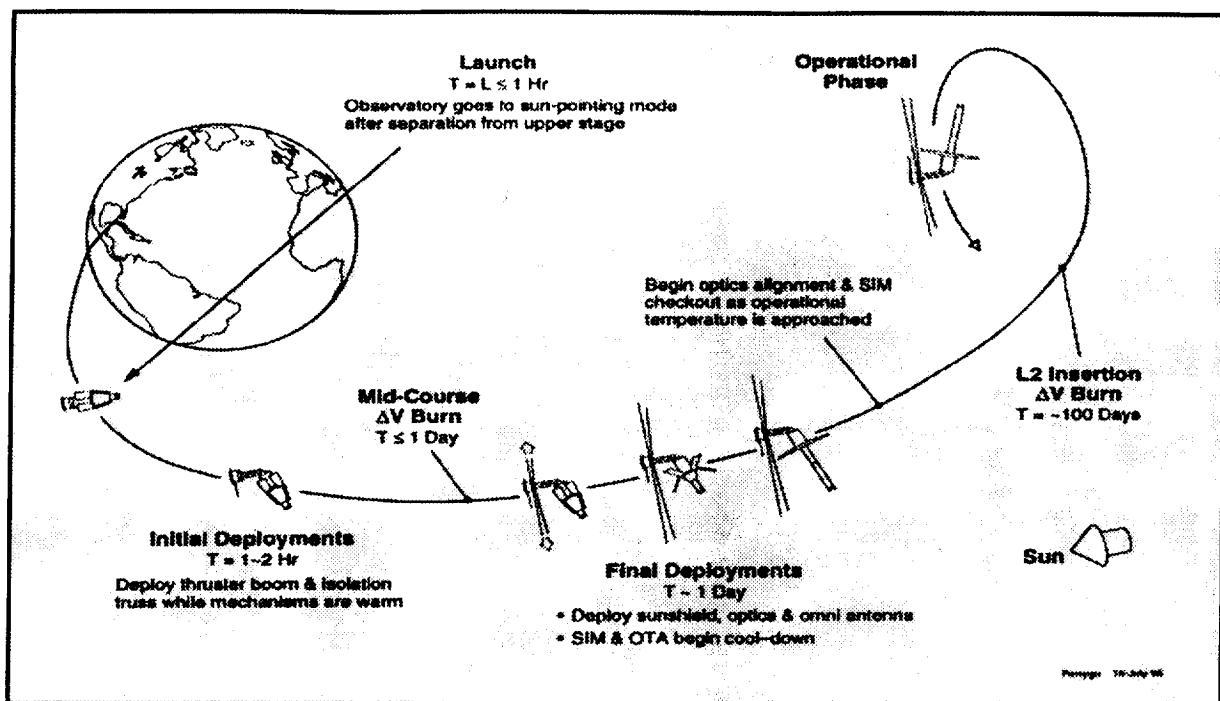
Figure 4 Launch & Early Ops Phase (L2 Transfer) Scenario

Because the mirror will be partially exposed before the petals are deployed, and then fully exposed once deployed, shielding from UV will also be required. To accomplish this, the deployment scenario will be adjusted to minimize exposure of mirror surfaces to sunlight and earth albedo. Issues surrounding the deployment include when to deploy: whether at the first possible opportunity after launch, just prior to starting cruise to L2, once NGST has arrived at L2, or at various times. For mechanical reasons, it is desirable to deploy as soon as possible, and while the observatory is still warm. A scenario established to provide for these concerns is shown in Figure 4 above, and a trade-off chart addressing the various methods of contamination control is shown in Figure 5 below.

| Mission Phase | Contamination Threat | Baseline Solution | Optional Solutions |
|---|---|---|---|
| Launch | Particle redistribution from fairing | • Clean exposed mirrors at launch site<br><br>• Clean fairing to level 200<br><br>• Super clean purge on fairing | Cocoon over exposed optics |
| After Fairing Separation | • UV polymerization on exposed surfaces<br><br>• Molecular and water accumulation on optical and thermal surfaces<br><br>• Unknown particles in ram | • Limit NVR to 250Å on optics at launch, confirm w/modeling<br><br>• Bakeouts & purging to minimize moisture absorption | Cocoon over exposed optics |
| Cruising to L2 | • No longer molecular redistribution concern because no line of sight from s/c bus to OTA after sunshield is deployed<br><br>• Minimal particle impingement concern: primary mirror not in direct ram | | |

Figure 5    Design Baseline and Optional Solutions for CC during launch and early on-orbit operations.

These issues notwithstanding, the sooner the spacecraft/truss, thermal/solar shield, and optical telescope assembly (OTA) are deployed, the greater the possibility of mirror exposure to either sunlight and earth albedo, which would cause polymerization of hydrocarbons. All of these issues will continue to be evaluated in order to determine the optimum deployment scenario. If molecular redistribution analysis shows that contamination redistribution and/or polymerization of hydrocarbons will be prohibitively detrimental to the mission, then the possibility of using a deployable cover remains an option. A cover is not in the current NGST baseline; however, concepts have been developed in order to prepare for the potential need to use a cover. Initial conceptual depictions of the cover are shown in Figures 6 and 7.
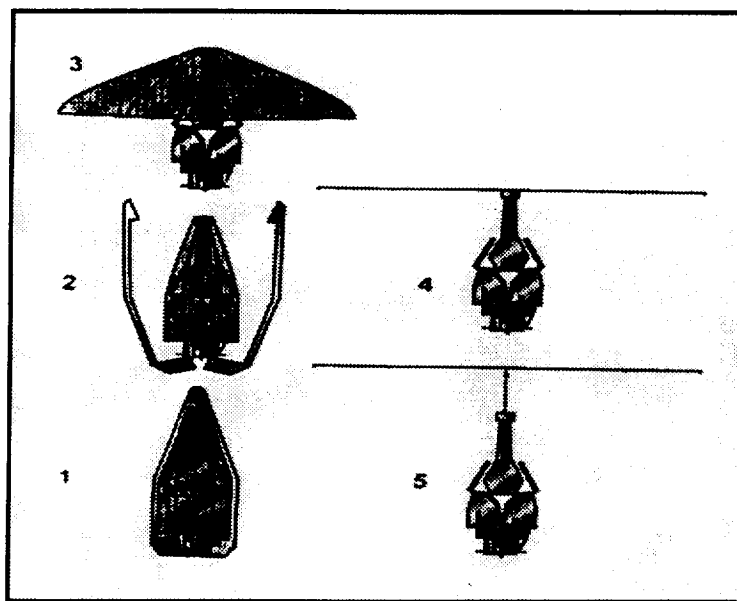


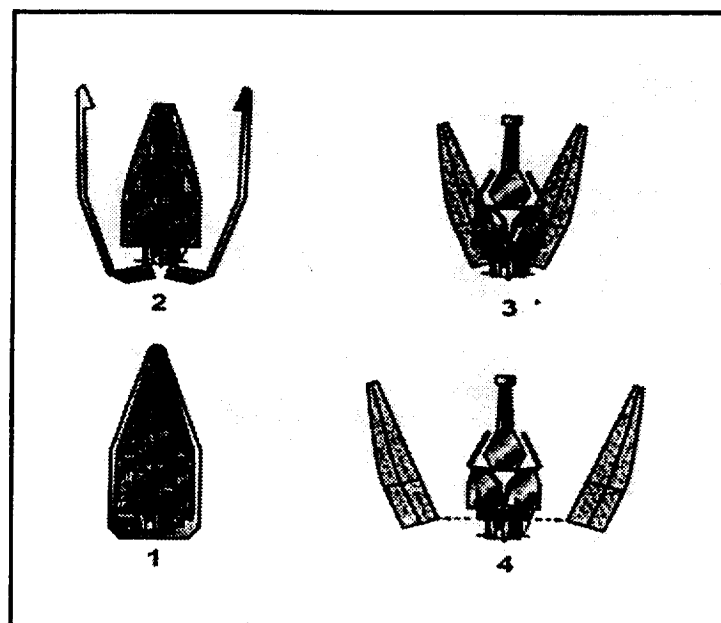Figure 6 - Contamination Shield (Cocoon): Fly-Away Concept



Figure 7 - Contamination Shield (Cocoon): Clam Shell Concept

## Other Contamination Issues

Outgassing was a concern initially identified both *from* and *for* the thermal/solar shield. Because the shield is so huge in area, even a small percentage of mass loss from the shield can translate into unacceptable levels of accretion onto the primary mirror. In addition, because the shield cools down to cryogenic temperatures on the telescope side, water can condense on its surfaces and degrade the emissivity.

The levels of accumulation on surfaces due to outgassing were evaluated by a preliminary contamination redistribution analysis, performed by Shaun Thomson. Analysis revealed that because the thermal mass of the sunshield – made of thin film sheets – was small, the shield cooled down very quickly. In contrast, because the thermal mass of the primary mirror was much larger, the mirror cooled down at a much lower rate. As a result, the level of water expected to accumulate on the mirror during initial cool-down was shown to be negligible. Conversely, however, if the sunshield were to warm up for any reason, outgassing from it would result in almost immediate accretion of water on the primary mirror.

The scenario presented was a worst case, assuming:
> Sunshield at 300K  *(Telescope-side)*
> Primary and Secondary Mirrors at 60K
> 25-layer MLI behaves similarly to the sunshield
> > *(This was the outgassing data set currently available to use in the analysis)*
> Sunshield to be unfurled 12 hours after launch

With these assumptions, deposition on the mirrors - almost entirely water - would be:
> Primary Mirror                Minimum of ~1Å and Maximum of 110Å
> Secondary Mirror 465Å

The conditions modeled were more conservative than those expected. In reality, the sunshield will not stay at 300K; rather, it will cool down to 60K in less than 2 hours. In addition, the primary and secondary mirrors will cool down much more slowly, according to thermal analysis performed by Chuck Perrygo of Swales and shown in Figure 8. Once the sunshield is cold, outgassing virtually stops. Over a lifetime of 10 years, only 0.12Å would be expected to accumulate on the mirrors if the telescope-facing layer of the sunshield remains at 60K.
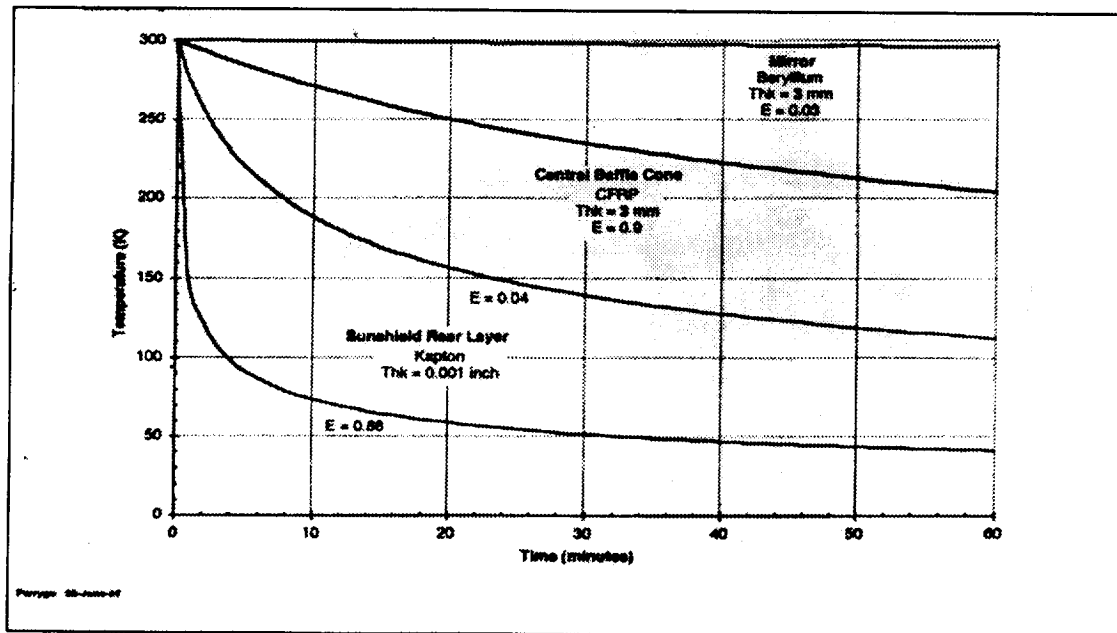


Figure 8  Relative cool-down rates of the Primary Mirror with respect to the Sunshield

Finally, the amount of water deposition that would be required to cause an appreciable difference in reflectance would be in the thousands of angstroms of thickness. This is based on BRDF measurements taken by the Arnold Engineering Development Center (AEDC) and presented in the report[3]: *Cryogenic BRDF Measurements at 10.6 μm and 0.63 μm on Contaminated Mirrors* (used with permission from Bob Wood). According to tests performed with various thicknesses of water on mirrors at 88K, the BRDF measurements did not change significantly until there was 8.45 μm (84,500 Å) of water on the mirror, as shown in Figures 9 & 10. The BRDF measurements were taken at 0.63 μm and 10.6 μm, both representative of the 0.6-30 μm wavelength range of NGST.
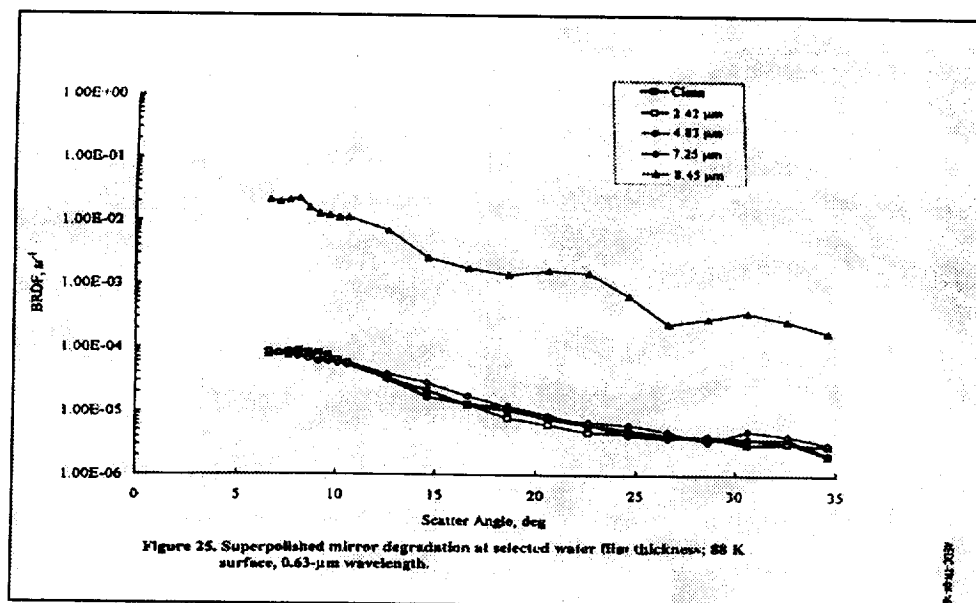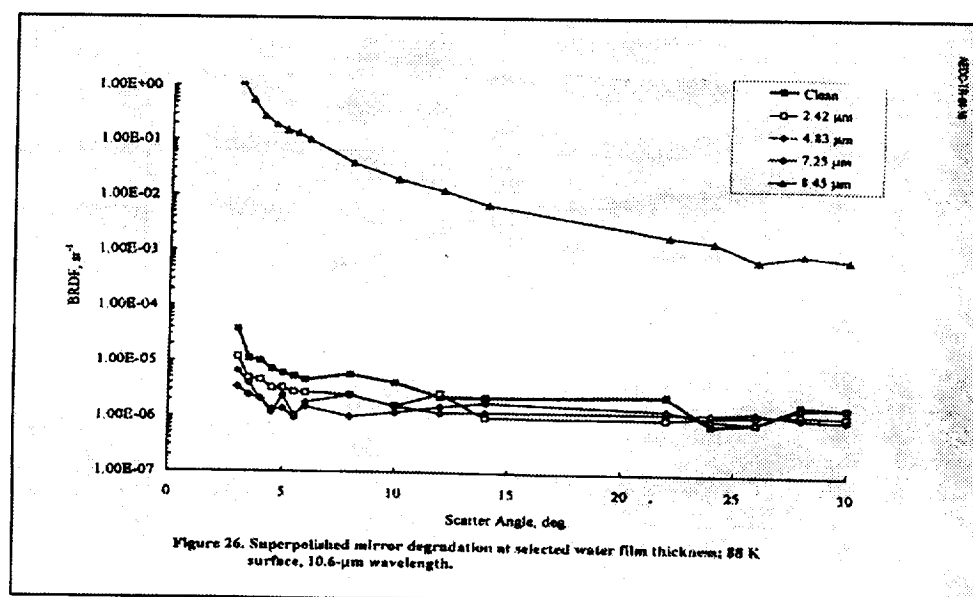


Figure 9



Figure 10

The highest accretion value determined by the analysis is that of 465Å on the secondary mirror. This would cause, at most, a 2% decrease in mirror reflectance. One question this raises is whether there are support surfaces around the secondary mirror that might cool more slowly than the secondary mirror. If so, the support surfaces may be an additional source of outgassing to the secondary mirror. Therefore, it will be important to evaluate the secondary mirror as soon as the support structure for it is defined and its coatings are determined.

In the future, it may also be useful to perform tests that are closer to the NGST parameters: for example with the mirror surface at 60K, or at wavelengths in the *core* requirement region of 2.7 µm to 5.0µm where water has a high absorption band. This data would also provide the thickness of water/ice required to cause fracturing of the ice layer at 60K. Fracturing of ice, i.e. breaking up of the surface, occurs at thicknesses of 1-10µm, depending on the temperature of the surface (according to Bob Wood, co-author of the AEDC report cited above). This fracturing causes an increase in scattering by 3 orders of magnitude; this is the phenomenon that causes the radical change from 7.25 µm to 8.45µm in the data shown in Figures 9 and 10. At this point, however, the Arnold Engineering data does indicate that it would take a much larger thickness of water than the primary and secondary mirrors will see to cause a problem with reflectance.

Finally, the current configuration locates all thrusters and vents on the warm side of the sunshield only. If it becomes necessary to locate thrusters on the telescope side of the sunshield for orbit operations, then scrutiny and analysis of the thruster operation shall be required in order to prevent thruster plume by-products from condensing on mirror surfaces. This is particularly relevant with mirror surfaces at 60K.

## 4. CONCLUSION

The NGST mission success is critically dependent on the maintenance of low contamination levels. The unique characteristics of the NGST, the science requirements and the magnitude of the optics, have provided one of the few times that contamination control has been seriously considered in the design phases of a feasibility study. The overall approach to NGST contamination control will require evaluation of design options and mission scenarios, analysis of choices made along the way, and testing of possible materials and configurations.

## 5. REFERENCES

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